Administration and Maintenance Plan

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(Manuscript received March 12, 1969)

The No. 2 Electronic Switching System has been planned with dependability, maintainability, and operational ease representing a major portion of the total system design concept. The major characteristics that fall under these headings are redundancy, trouble detection, trouble recovery, diagnosis, repair, man-machine interface, data protection, and operational and administrative procedures for growth and change. All these factors play a large role in both the hardware and software portions of the system design. This article reviews the highlights in each of these areas and describes how they interact in the overall system across both the control complex and peripheral system areas.

I. OBJECTIVES

A successful local switching system must be dependable as seen from the customer's viewpoint and economical to maintain and operate as seen from the telephone company's view. This performance must be achieved under the stress of a variety of central office environmental constraints—physical (temperature, humidity), electrical (noise, commercial power interruption), traffic (overload), office growth (addition of lines, trunks, networks, stores, and so on), and human errors. The design of a switching system such as No. 2 ESS must then take into account all of these factors in achieving the proper balance between equipment first costs and annual operation and maintenance costs, while also meeting customer service standards.

1.1 *Dependability*

The customer measures a system's dependability in service continuity and accuracy of call handling (dialing, billing, and so on). The design objectives are, therefore, continuous high quality service

24 hours a day for a 40-year life. Specific reliability objectives are that total system down-time (time during which customer service is noticeably degraded) should not exceed two hours during its 40-year life and that, on the average, not more than 0.01 percent incorrectly handled calls should result from system troubles and errors. Furthermore, from a customer's service viewpoint, under trouble conditions it is preferred that service degradation peaks be avoided—a few calls handled incorrectly occasionally or a few very brief outages per year causes less customer inconvenience than less frequent but longer duration service difficulties and interruptions.

In order to achieve this degree of dependability, attention must be paid both to the operation and administration of the system when it is functioning normally, and to its maintainability in the face of trouble.

1.2 *Operation and Administration*

While processing calls, the switching machine must also monitor its own performance in terms of traffic measurements of calls handled in service, and of calls aborted, because of shortages of switching or trunk facilities. In addition, plant measurements of aborted calls and associated trouble conditions are necessary to provide an indication of the machine's health. This data, in hard copy, direct-reading simple formats, provides the basis of much of the craftsmen's actions in the day-to-day operation of the system.

In a stored program switching system, reassignments and additions of trunks, for example, may involve hardware changes, translation memory changes, and updating of administrative forms. Other classes of change items include customer line assignments (frequent but relatively simple) and the addition of major growth items such as networks and stores (less frequent but more complex). Experience has shown the importance of carefully human engineering these procedures since human intervention is often the source of system trouble rather than conventional component failures.

1.3 *Maintainability*

The actual process of trouble detection, system recovery, diagnosis, repair, and service verification is broadly classed in the maintainability category. In order to achieve the required dependability, the design must stress:

(*i*) Use of long-life components and adequate circuit margins.

(*ii*) A redundancy plan sufficient to keep the system operational in the presence of component failures and human intervention for administration and growth.

(*iii*) Trouble detection mechanisms (hardware and software) for all service effecting parts of the system, either automatic, routine, or, at worst, manual.

(*iv*) Rapid recovery of the call processing function and protection of the calls in progress in the face of either hardware, software, or human intervention (procedural) difficulties.

(*v*) Diagnosis and isolation of troubles (both hard faults and transients) either by automatic (programmed) machine analysis of data or by manual means.

(*vi*) Repair and verification procedures which allow for requested repetitive testing of trouble items, simple mechanical procedures, and automatic recheck on service restoral.

(*vii*) In general, a high level of human engineering in all displays, controls, teletypewriter communications, and operational procedures in which the craftsman interacts with the machine—hopefully with a view to keeping these items as similar as possible between different switching systems.

1.4 *Centralized Maintenance and Administration Facilities*

The inherent reliability of solid state components and good circuit design result in a significantly lower trouble rate than that experienced by comparable electromechanical systems; however, the complexity, high speed of operation, loss of the ability to audibly and visually observe apparatus operation has tended to increase the skills required by plant craftsmen to restore system operation and locate those troubles which the machine cannot handle automatically. In addition, the low trouble rate experienced does not give craftsmen sufficient practice to maintain their proficiency.

To overcome these possible problems and to take advantage of the great potential for annual cost savings, facilities and procedures should be provided to allow remote administration and maintenance control. Such facilities allow a small group of well-trained craftsmen at a centralized point to provide administrative and maintenance coverage to a number of ESS type offices almost equal to their being physically in each office. The amount of trouble hunting experience, at this point, should assure continued craftsman proficiency. Many actual repair operations, running of cross connections, and other tasks

requiring physical contact with the equipment may be taken care of by semiskilled craftsmen, either dispatched from a central point or, if the work load is adequate, by assigning such craftsmen to the office on a schedule.

The centralization of such facilities can also allow specialization of functions in convenient locations. For example, the plant service center would have direct access to a teletypewriter for making customer line change translations to any of several offices. And the traffic department could have access to data from several offices at one central location.

In summary then, the objectives of dependability imply the need for a high level of maintainability and operational ease, and the demands for economy can be substantially aided by centralizing these functions.

II. GENERAL ADMINISTRATION AND MAINTENANCE PLAN

The dependability, adminstration, and maintainability objectives, when applied to stored program switching systems, define the need, in computer terms, for an on-line real-time, high availability machine. To achieve this economically requires careful initial systems planning in basic redundancy configurations, in man-machine interface capabilities, and in hardware-software tradeoffs. Though difficult to allocate precisely, it is estimated that approximately two-thirds of the total program is dedicated to a system of maintenance and administrative programs that are used to administer system redundancy, control detection, and diagnostic routines, make performance measurements, and provide for communication with the craftsman. It is the need to keep the switching system operational during periods of growth and change of customer services (major hardware, program and translation additions and changes), the need to keep calls being processed during switches to standby equipment (preservation of transient data), and the requirement of providing simultaneous on-line communication with a number of craftsmen, that adds extensively to the program structure and makes maintenance more than simply a matter of diagnostics.

2.1 *Basic Redundancy Plan*

As described in Ref. 1, the entire control unit (program control, program store, call store, input-output and peripheral bus system) is considered as a single entity which is duplicated. Two control units,

plus the maintenance center, comprise a control complex. Since the component count and failure rates are sufficiently low, no reconfiguration within a control unit is necessary, thus simplifying both the hardware connections and controlling programs. The maintenance center is unduplicated except for the existence of multiple teletypewriter channels (eight maximum) which serve a variety of different functions. In the peripheral equipment, network and scanner controllers and supplementary central pulse distributors are duplicated since failure here can effect large numbers of lines. Network fabric, trunks, junctors, and service circuits are traffic-engineered items and thus contain inherent redundancy.

In order to provide rapid recovery from troubles and effective continuity of service, the processors normally are run in synchronism. This enables the off-line processor to keep its registers and call store contents continuously up to date and thus constantly available to take over on-line functions. This synchronous mode of operation involves providing all inputs (both normal scanning and peripheral maintenance responses) to both processors, while deriving outputs only from the on-line machine. Since network and scanner controllers do not have the long-term memory functions associated with processors, their duplicate mates are operated either in a traffic load shared state or in an idle stand-by condition.

2.2 *Man-Machine Interface*

The major communication between the switching machines and the craftsman is by teletypewriter. In addition, audible alarms and visual displays are used to alert the craftsman to trouble conditions which are subsequently more fully reported on a teletypewriter channel. Manual controls are available on the maintenance center for performing special tests on out-of-service equipment and for taking restart action when the system has lost its "sanity" to the point where it can no longer interpret teletypewriter input commands.

2.2.1 *Teletypewriter Facilities*

The system program is organized and the hardware is arranged for a maximum of eight teletypewriter channels. Each of these channels can be programmed to produce only certain classes of messages and to accept only a limited class of requests. Any one of these channels can operate a remote teletypewriter by the use of a data set. A typical installation might include four teletypewriters:

(*i*) Channel 1—local maintenance

(*ii*) Channel 2—remote maintenance

These channels report all system maintenance activity (troubles detected, diagnosis results, plant registers, and the like) and accept *all* system input messages (maintenance and other).

(*iii*) Channel 3—service order

This channel operates a remote teletypewriter at the plant service center which is used to input changes in customer line information (class of service, features, directory and billing numbers, and so on).

(*iv*) Channel 4—traffic

This channel provides traffic data according to a defined schedule (items such as trunk group usage, call rate, and dial tone delay). Specific data can be requested and the schedule can be changed by input messages on this channel.

All channels have built-in maintenance checks on each message and each one is arranged to provide automatic message transfer to an alternate channel in case of failure. Alternate backup channel definitions can also be changed easily.

2.2.2 *Display and Manual Controls*

In addition to teletypewriter information, the maintenance center has quick reference visual displays of items such as system alarm status, processor on- off-line status, and processor, trunk, and peripheral unit trouble indications. It also has a dynamic display of the characteristic program loop (program address register).

Manual controls available to the craftsman can be divided into three basic categories:

(*i*) The most frequently used in normal operation are associated with a trunk test panel facility. Trunk testing arrangements provide for switched access to trunks and for measuring dc and ac signaling, transmission, and noise parameters. To use them, a craftsman activates special panel keys, a *Touch-Tone*® telephone key set, and a teletypewriter.

(*ii*) Facilities on the maintenance panel provide various tests on both the on-line and the off-line processors. Available off-line facilities include the ability to step through programs or whole routines, to interrogate and load registers and call store locations, and to preset condition (address) traps by use of the comparator. On-line functions include dynamic visual register and store displays, and

preset condition program interrupts which can provide snapshot teletypewriter dumps. In addition, controls are provided to vary margins (threshold) in both off-line call and program stores.

(*iii*) Manual restart controls are provided as a final backup when more normal communications fail. Included are such items as forcing and locking either control unit on line, and initiating memory (call store) clearing operations to restart the system when it loses "sanity."

2.2.3 *Documentation*

The use of all these man-machine facilities is built on a hierarchy of documents with which the craftsman must be familiar.

The first is the *Input Message/Output Message Manual* which defines all possible teletype messages which are programmed into the machine and lists all acceptable input requests and the expected system response to them. Figure 1 shows a typical input message entry. This one is used to update the system calendar and each variable field is fully defined in the manual.

```
                                                      UB SY:DAT
1.  INPUT MESSAGE FORMAT

     UB SY:DAT:mon day year b!

2.  EXPLANATION OF MESSAGE

     Used to enter the current date into the system

     UB =Utility Base level request.  The request will be
         performed immediately.
     SY = SYstem
     DAT = DATe

     mon = month of the year (1-12 decimal)
     day = day of the month (1-31 decimal)
     year = year - decimal, last two digits
     b = day of the week - decimal 0-6. Sunday is 0

3.  SYSTEM RESPONSES

     OK = message was OK. It was accepted and the work requested
          has been accomplished.
          If the message came from paper tape, the tape re
          be turned on.

     NG = the message was not accepted (N
          action or data fields were
          system state may not
          procedures   or
          the
```

Fig. 1 — Sample *Input Message Manual* description: system calendar update.

When the output message gives specific diagnostic data, this *Manual* points to a *Trouble Locating Manual* (see Fig. 2) which translates the data field of the message (*Trouble No.* column) into a specific set of suspect circuit packs. Brief remarks are incorporated to describe the trouble area functionally. Should this information prove inadequate (that is, replacement of packs does not clear the trouble), subsequent sections of the *Trouble Locating Manual* are arranged to give a detailed functional description of the test and an interpretation of the digits in the trouble number. Repair procedures might then involve reference to the more basic maintenance documents, including program listings and schematic drawings. Experience indicates that better than two-thirds of the troubles should be cleared through use of only the simple trouble number translation.

A series of *Bell System Practices* are provided as basic training documents and give overall system descriptions in addition to detailing all operational and administrative procedures the craftsman must perform. These documents contain extensive cross references.

```
    BELL TELEPHONE LABORATORIES, INCORPORATED

      TROUBLE NO.        EQUIP LOC - TYPE              REMARKS
           (CONT)
                         10-132-30A  A440
                         I0-132-28   A440

                         I0-132-19   A440
                         I0-032-38   A408
                         I0-032-36   A403

      3812               FAILURE OF 2 CPD TRANSLATION FROM THE EA

      3812 000001        I0-030-46   A403
                         I0-030-47   A401
                         I0-030-48   A438
                         I0-030-43   A403

      3812 000002        I0-030-46   A403
                         I0-030-47   A401
                         I0-030-48   A438
                         I0-030-43   A403

      3812 000003        I0-030-46   A403

                                      (CONTINUED)
    ESS NO.2 - ******************************* ISS **     TLM-*****-D513
```

Fig. 2 — Sample *Trouble Locating Manual.*

2.3 *Programming Organization*

In order to control all the maintenance, communication, and administration functions described above, the program structure is organized into a hierarchy of tasks performed at base level times and interrupt times. In addition, an initialization, or restart, procedure is provided under certain circumstances, resulting in a break in the continuity of program flow.

2.3.1 *Base Level Programs*

All deferable, or low priority, maintenance tasks are handled at the end of the normal call processing transient call record scan.[2] Items covered here regularly include processing the waiting list of incoming and outgoing teletypewriter messages, including such functions as timing, format translation, and distribution of messages to client programs.

The base level maintenance monitor program determines which additional tasks are to be performed. The normal sequence of these tasks may be modified by any maintenance activity that has taken place since the last transient call register scan. For example, if a check circuit output has automatically switched out and inhibited a processor, this fact is taken into account here and diagnostics on the off-line take preference over lesser periodic routines. Similarly, manual requests may have a higher priority. One or more of the following functions is performed at this time:

(*i*) Execution of any manual (teletypewriter-inserted) requests such as demand tests or make-busy functions.

(*ii*) Updating of off-line call stores after an interval of non-synchronized processor operation.

(*iii*) Diagnostics on the processor and on peripheral units as a result of calls from trouble recovery routines or manual requests.

(*iv*) Short-term periodic routines performed on a schedule, including items such as processor trouble detection programs and initiation of trunk tests.

(*v*) Long-term periodic routines intended to exercise those circuits not used in normal operation, primarily check circuits and on-line/off-line switching facilities.

(*vi*) Miscellaneous functions, including error count tabulations in the call store (such as plant registers), directed scans of various ferrods assigned to maintenance functions, and control of maintenance center displays.

2.3.2 *Input-Output Interrupt Level Programs*

In addition to the scanning, digit receiving, and outpulsing functions that call processing handles during the periodic 25-millisecond input-output interrupt routine, maintenance functions requiring close timing are also executed here. Items covered here include:

(*i*) Trunk and service circuit tests requiring precisely timed actions are executed first to avoid stagger resulting from variable execution time in the various parts of the interrupt program.

(*ii*) The network controller's maintenance ferrods are checked for proper operation based on the previous interrupt's actions. Failures result in peripheral order buffer retries and eventual call teardown if no working mode is found.[2] The base level routine is notified of the troubles in order that diagnosis may be initiated later.

(*iii*) All teletypewriters are scanned for new inputs and new characters are outputted to active teletypewriters.

2.3.3 *Maintenance Interrupt Level Program*

The maintenance interrupt has the highest priority. It is initiated by processor mismatches as detected by the call store comparison in the maintenance center, by some peripheral unit and input-output errors, and by manual request. All three sources come in at the same priority level and block each other until their respective tasks are complete. These error signal interrupts immediately initiate trouble recovery programs and after the appropriate recovery actions (for example, switch of on-line/off-line control unit configuration or scanner controller) the problem is passed on for further resolution to the lower priority base level programs.

2.3.4 *Initialization Restart*

If the processors switch their on- off-line configuration while the off-line is out of synchronism, or if they go into a multiple switching mode from which they cannot recover, the program is restarted from a fixed location to provide an orderly return to the beginning of the call processing monitor cycle. The initial source of the trouble may be either hardware or software difficulties. A count of the number of restarts incurred during a given time is used to progressively clear out the call store until the system recovers its "sanity." This strategy involves clearing or releasing various transient and maintenance only locations of call memory while preserving most stable talking path

records. An initialization restart of this type may also be manually initiated, including a complete call clearing capability when necessary.

III. ADMINISTRATIVE FUNCTIONS

A particular telephone office is defined to the call processing programs by a series of parameters and translation tables in program store that describe that office's network traffic characteristics, trunking facilities, routing and charging constraints and all individual subscriber definitions. The initial office traffic and trunking engineering is performed as a result of the operating company's analysis of needs and results in ordering the proper equipment frames for initial installation. All program store translation and parameter contents for initial service are processed by means of an Office Data Assembler program in a general purpose regional computation center.

As time passes, the typical office evolves and grows, and individual subscriber definitions change as people move and new services are offered. In order to respond to these changes, a series of administrative (recent change) programs are resident in the No. 2 ESS machine to permit a virtually continuous memory updating capability. Subscriber changes are generally originated by way of the plant service center, while network and trunking modifications are based largely on the traffic measurements performed by the processor on its daily calling rate pattern, and on operating company projections. In the case of major equipment growth additions, translations are changed by means of a new Office Data Assembler run.

In addition, another class of administrative functions known as plant measurements are maintained for each office. These involve both service measurements to reflect actual effects on service as seen by the customer (for example, total customer receiver time-outs) and performance measurements to reflect the basic health of the machine in terms of such items as failure and error counts of various pieces of equipment. These measurements are useful in directing attention to areas where additional maintenance effort appears justified.

3.1 *Traffic Measurements*

Traffic measurements are made throughout all phases of the call processing programs and are recorded in call stores. Data are put out through a dedicated teletype channel on assigned quarterly, hourly, daily, and weekly schedules, or on demand. Various combinations of the three basic types of measurements (peg counts, usage,

and overflow) are performed in such areas as networks, junctors, service circuits, trunks, and office calls. Their usefulness can perhaps best be described by some examples.

In the network, usage counts are maintained for each concentrator for use in load balancing and line assignment. In the junctor area, usage counts are kept on wire and circuit junctor groups for load balancing between networks and for intraoffice-interoffice call rate measurements. Trunk measurements are made for each group with various combinations of peg count, usage, and overflow in outgoing, incoming, and two-way categories. Usage counts are also made on subscriber items such as the various custom calling services.

When these data indicate the need for relatively minor reconfigurations without major hardware additions, translations are changed by local recent change procedures in the No. 2 ESS machine. In other cases, more elaborate processing is required at a regional computation center.

3.2 *Recent Change Procedures*

The types of items that fall in the recent change category include service orders (subscriber additions and changes), trunk additions, service observing, addition of new routes, and changes in office code treatment. The service orders are usually remotely entered from a plant service center; the other items are performed locally by the craftsman from the maintenance center teletypewriter. Again, an example will perhaps best describe the process.

The original office record input forms (Fig. 3) indicate that directory number 736-0056 is vacant. A new line is to be added. The information to be inserted includes this chosen vacant code together with its assigned terminal equipment number, associated billing number, desired features (dial transfer and add-on conference) and line class code (1FR single party, flat rate, residence). This information is keyed in on the service order teletypewriter channel as shown in Fig. 4 in the standard universal service order code input language. This information is processed by the No. 2 ESS, checked for validity, converted into its binary equivalent, and stored in a special call store recent change buffer.

The call store buffer, with a capacity of 512 updated program store words per module of permanent magnet twistor translation storage (16,384 words), is searched by the call programs for changes each time its associated permanent magnet twistor translations are ac-

DIRECTORY NUMBER RECORD
CONVERSION
NO. 2 ESS

ESS 2100
TEL CO 002 (3 4 5)

OFFICE CODE 736 (17 18 19)

BASE & CONTROL NO. 77716 (6 7 8 9 10 11)

HUNDRED 00 (20 21)

ESS UNIT 736

FORM CODE 14 (15 16)

DIRECTORY NUMBER 22 23	TERM EQUIPMENT NUMBER: NET 25 26	CONC GROUP 27	CONC 28	SWITCH 29	LEVEL 30	RATE AREA 31	PARTY NO. 32	CLASS INFORMATION: LINE CLASS CODE 33 35	EQUIPMENT: LCA 36	TES 37	TTC 38	39	40	FEATURES: 41	42	AD2 43	ADI 44	ADO 45	CWT 46	DTR 47	SUPPL INFO: PAGE 48 51	ITEM 52 53	REMARKS 54 80
50	05	2	5	1	2	1		1FR	✓									✓					
51																							
52	02	6	3	5	1	0		1MR			✓						✓						
53																							
54	01	1	2	1	3	0		1MB			✓					✓				✓			
55																							
56																							
57	03	1	7	2	3	1	2	2MR								✓			✓		0003	05	
58																							
59																							
60																							
61																							
62																							

Fig. 3 — Sample office record input form.

```
A RC SØ/         <---ADMINISTRATION RECENT CHANGE SERVICE ORDER.
TYP NEW/         <---TYPE NEW LINE.
IN 736 D056/     <---TELEPHONE NUMBER.
TEN 022200/      <---TERMINAL EQUIP NUMBER (NW#,GROUP,CONC.,SW.,LEVEL)
BTN 736 D050/    <---BILLING TO NUMBER.
FEA DTR ADD/     <---FEATURES: ADD-DIAL TRANSFER.
FEA ADØ ADD/     <---FEATURES: ADD-ADD ON CONFERENCE.
LCØ 1FR! ØX      <---LINE CLASS CODE - SINGLE PARTY, FLAT RATE, RESIDENCE
```

Fig. 4 — Sample recent change teletypewriter service order input message.

cessed. As changes and additions accumulate in the buffer, an output indication is given on the teletypewriter that the maximum capacity is being approached and that action should be taken to update the permanent magnet twistor magnet cards. This is accomplished by means of the single card writer contained in the maintenance center frame.[1]

The contents of the recent change call store buffer are analyzed by program and translated into the affected set of permanent magnet twistor cards (128 words per card) which are identified in a teletypewriter message upon request. These selected cards are individually inserted in the single card writer and the entire card is magnetized by a program that copies the old on-line translation plane from permanent magnet twistor with all appropriate call store buffer recent change entries incorporated. When all affected cards have been magnetized, they are inserted in the off-line program store, and automatically verified against on-line program store plus call store change buffers. If successful, the on-line/off-line processors are switched, the procedure is repeated, and the call store buffers are cleared to allow for accumulation of the next group of changes.

Depending on office size, rate of change, and local office manning practices, this translation updating procedure may be performed perhaps every two weeks. In larger offices, more automatic translation updating procedures would be provided if the change rate warranted it. Throughout the process, office record forms must be kept up to date in order that future changes do not create conflicts.

3.3 *Major Translation Change Procedures*

Certain translation changes require a simultaneous change of large blocks of data, plus extensive validity tests and error checking on the input data. In some cases, even with reasonable amounts of data, the translator structure is sufficiently complex to make the relatively simple recent change program inadequate. The changes which fall in these categories are situations which require major office equipment growth (network frames, trunk frames, storage additions, and so on),

major revisions in routing, screening, and charging translations, and general reorganization of existing translator origins as additional storage is added.

In all of these cases, the problem can usually be anticipated well ahead of time and so the rapid response characteristic of the recent change procedure is not essential. As a result, use is again made of the Office Data Assembler program as shown in Fig. 5. Used here in its update mode, the office data assembler program accepts new punched input forms, validates and error checks them, and incorporates the data into the existing office translators. To ensure that the actual No. 2 ESS office translator being updated is consistent with the administrative forms, the Office Data Assembler operates on an actual dump of the program store contents, and is capable of providing a new set of adminstration records.

IV. CONTROL COMPLEX MAINTENANCE

The control complex, as stated earlier, consists of two control units and a maintenance center. Only two configurations of control complex equipment are possible: either one of the control units on-line

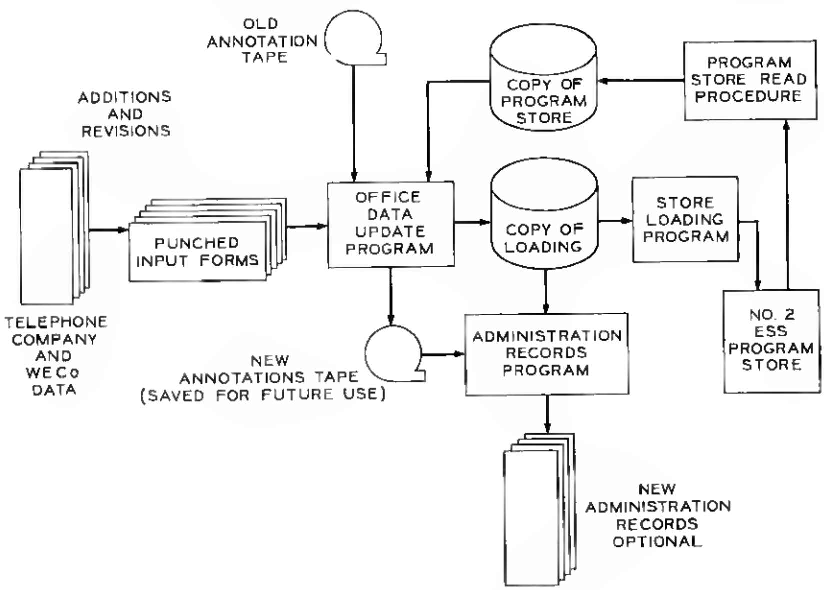

Fig. 5 — Initial loading and growth processing of office data.

(controlling peripheral equipment) and the other off-line. Normally, the two control units are running in command synchronism with only the on-line control unit actually performing a controlling function.

Problems occur in control complex operation when either a solid or marginal circuit fault occurs. Both maintenance circuits and programs are used to detect a trouble condition, to recover a working system, and finally to either determine that a transient error occurred or to diagnose what circuit fault exists. Figure 6 summarizes how troubles are detected and what happens after a trouble is found.

Maintenance circuits and programs can handle a wide variety of different faults. For example, programs and circuits used in fault diagnosis are designed to handle faults commonly encountered in the high-speed transistor resistor logic used in No. 2 ESS. These faults include: (*i*) open and shorted semiconductors, (*ii*) open resistors, and (*iii*) open connector contacts on pluggable circuit packages.

Programs and circuits which recover a working system after a fault occurs can handle not only these faults but also faults which cause

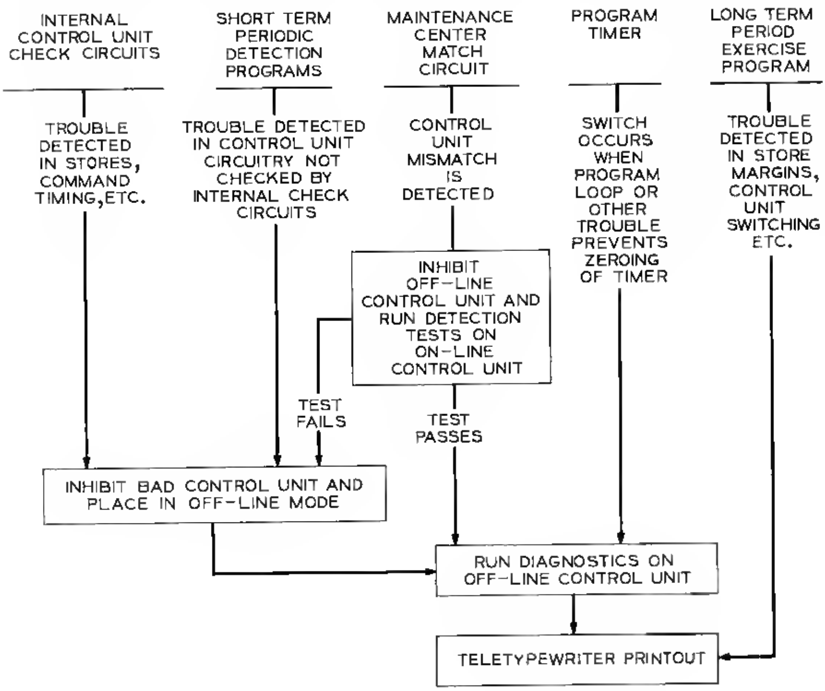

Fig. 6 — Control complex maintenance.

marginal circuit operation or faults such as wire opens or wire crosses which should not occur frequently.

4.1 *Trouble Detection Methods*

A combination of check circuits and program tests are used to find circuit troubles as shown in Fig. 6.

4.1.1 *Check Circuits*

Typical internal control unit check circuits detect problems such as store access faults and automatically attempt to recover a working system by switching control units if a fault is detected in the on-line control unit. Check circuits are used when program tests cannot detect a fault fast enough or reliably enough. For example, the call store access check circuit detects faults such as shorted access diodes which cause marginal store operation. This class of faults cannot be solidly tested by any type of program check.

A maintenance center check circuit compares the call store input registers in the two control units when call store operations are performed in synchronism. A fault or transient error in almost any part of either control unit quickly results in a call store input register mismatch since almost all tasks performed in both the program control and input-output involve call store writing. A check circuit mismatch signal interrupts the program currently being run and causes a trouble recovery program to be called in which attempts to find the faulty control unit and place it in the off-line mode. This trouble recovery program is described in Section 4.2.

Each program control contains a program timer circuit which is designed to backup other detection methods. Normally, an on-line control unit program zeroes a counter in both program timers at least once every 300 milliseconds. If, however, a trouble condition exists such as a program loop which prevents a timer from being zeroed (within 320 milliseconds for the on-line and 640 milliseconds for the off-line), the timer will time-out and automatically produce a switch. The new on-line control unit is automatically forced to run an initialization restart program which attempts to establish a working system.

4.1.2 *Program Detection*

Short-term periodic program tests detect the same troubles found by the mismatch trouble recovery program since exactly the same program tests are run. These tests are continually run interleaved with

call processing, and detect faults within approximately five seconds, compared with microseconds in the case of the comparator circuit. These tests provide trouble detection even when the control units are not being matched and provide a backup to the comparator check circuit. In fact, if very rapid fault detection were not required, it would not be necessary to have a comparator circuit.

Detection program testing of the input-output presents a special problem since this unit is normally operating independently of the program control. The program control has to stop the input-output, save, test, and restore input-output registers, and restart the input-output each time an input-output detection test is run in order to prevent interference with normal input-output operation.

Long-term periodic exercise programs perform tests on circuitry not normally checked by other detection means. For example, both the off-line program and call stores are placed in marginal modes and tested for correct operation. This is accomplished by applying high and low values of threshold voltage to store readout amplifiers at the same time words are read out and checked for correctness. This check attempts to force store problems to show up before they can affect actual system operation. In addition to store margin tests, the complete diagnostic test sequence as well as a test of control unit switching is performed to force troubles to show up in circuits not exercised in normal system operation.

An additional periodic check on correct system operation is performed by the base level maintenance monitor which checks the system state once each program scan by looking at certain key flip-flops. If an abnormal state is found, a trouble has occurred and diagnostics are called in. For example, diagnostics are called in if the off-line control unit is found inhibited and not running programs when it is supposed to be running in synchronism with the on-line control unit.

4.2 *Trouble Recovery*

After a trouble is detected, automatic circuits and, in some cases, trouble recovery programs are used to obtain a working system. The physical action taken to restore a working system is very simple as a result of the simple split redundancy. If a fault is found in the on-line control unit, control units are switched and the new off-line control unit is inhibited from running programs. If, on the other hand, a fault is found in the off-line control unit, the only action

taken is to inhibit the off-line control unit. These actions are automatically initiated when faults are detected by control unit check circuits or by programs. After trouble recovery action, the base level maintenance monitor will automatically call in diagnostics when the off-line control unit is found inhibited.

4.2.1 *Mismatch Detection Programs*

A special mismatch trouble recovery program is run in the on-line control unit after a mismatch to determine if the on-line control unit contains a fault. This program first inhibits the off-line control unit and then calls in detection tests. These detection tests are identical to those run during short-term periodic detection. However, all the tests are run at once instead of being interleaved with call processing in order to minimize test time. Tests are run in a sequence which attempts to test as much circuitry as possible as quickly as possible (all tests are run within 100 milliseconds). As a result, functions tested first are those which exercise the most circuitry. Actually, a large amount of circuitry can be assumed to be good at the beginning of the mismatch detection test, since many failures are detected by internal control unit check circuits rather than by the maintenance center match circuit.

If a solid fault in the on-line control unit is detected by a mismatch detection program, a control unit switch is automatically generated which inhibits the new off-line control unit and uninhibits the new on-line control causing an initialization restart program to be run in it. The new on-line control unit will be slightly out of date since no new inputs were recorded in its call store while mismatch detection programs were being run; however, it will not contain erroneously processed information. Shortly after the switch, the base level maintenance monitor will call in diagnostics when it finds the off-line control unit inhibited.

If the on-line control unit successfully passes all detection tests, diagnostic tests of the off-line control unit are called in. These tests attempt to determine if an off-line control unit fault caused the mismatch. Diagnostic test failure results in formation of a teletype printout which attempts to pinpoint the location of the fault. Successful completion of all diagnostic tests indicates a transient error condition caused the mismatch. If this is the case, control units are placed back in synchronism and one is added to a call store word containing the number of all test pass conditions.

4.2.2 *Peripheral Unit Trouble Recovery Programs*

Certain faults in the input-output unit do not result in control units mismatching but instead cause peripheral units to be accessed improperly. Detection of these faults by certain internal input-output unit check circuits cause peripheral unit trouble recovery programs to be called in. These programs, described in detail in Section V, attempt to recover a working system by retrying peripheral orders plus switching peripheral and control unit equipment if necessary.

4.3 *Diagnostics*

Diagnostic programs are automatically called in by the base level maintenance monitor after trouble detection and recovery has been completed or can be manually requested via the teletypewriter. The objective of diagnostic programs is to produce a teletypewriter printout which isolates a fault to as small an area as possible. The following paragraphs describe circuitry and programs which are used to achieve this.

4.3.1 *Maintenance Circuitry Provided for Diagnostic Testing*

Special control unit circuitry is provided to allow diagnostic tests to resolve the location of faults to a relatively few number of circuit packs. External maintenance commands allow the on-line control unit to control and monitor actions performed in the off-line unit. As shown in Fig. 7, the contents of on-line control unit registers can be gated to off-line registers or vice versa. Also, control functions such as starting and stopping the off-line control unit can be performed. This can be accomplished by resetting (to start) or setting (to stop) the off-line inhibit flip-flop. Figure 7 shows examples of two different external commands. One command executed in control unit 0 causes a register in that unit to be gated to a register in control unit 1 via the program gating busses. The other command starts control unit 1 by zeroing the inhibit flip-flop.

In a typical diagnostic test, the on-line control unit uses external commands to test off-line circuitry as follows:

(*i*) Stop the off-line control unit, initialize command timing and gate a program command directly into the program store output register.

(*ii*) Execute the command present in the off-line program store output register.

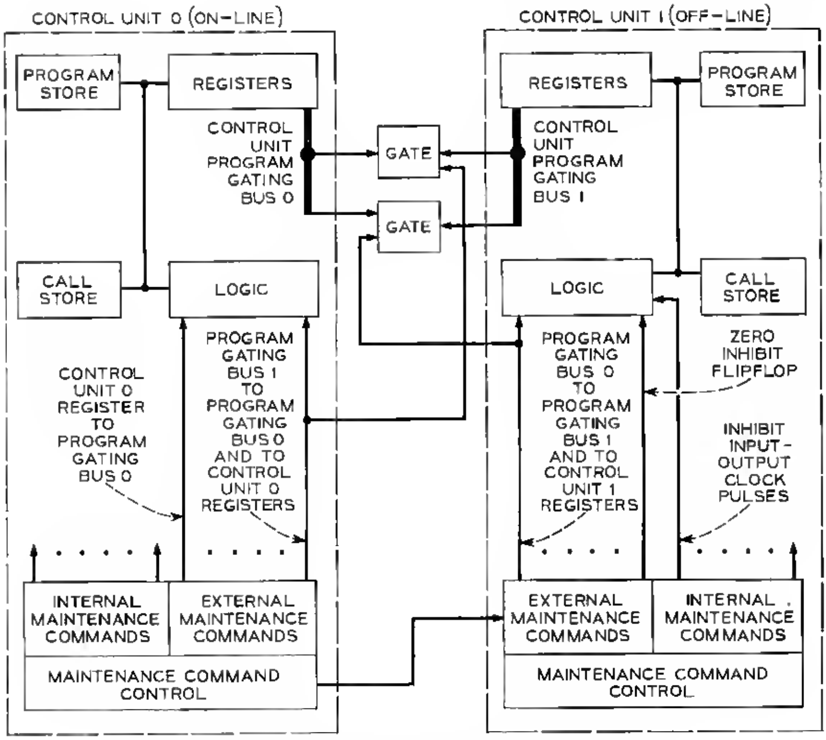

Fig. 7 — Typical diagnostic program commands.

(*iii*) Look directly at an off-line register to see if the command was executed correctly.

This testing method allows off-line control unit circuitry to be tested by the on-line control unit without having to rely on the correct operation of a large amount of off-line circuitry, including the off-line program store.

Certain internal maintenance commands executed by the off-line control unit are also used to aid diagnosis. These commands can either be executed under direct control of the on-line control unit as outlined above or as part of a program sequence controlled by off-line internal command logic (the command is read out of the off-line program store). In this second case, external commands are only used to establish an initial off-line program starting address, to start the program sequence running, and to look at test results after off-line testing is completed.

Internal maintenance commands are used to test areas such as the input-output unit which are not accessable to normal internal commands. For example, a typical input-output diagnostic test uses an internal maintenance command to set a flip-flop which prevents clock pulses from enabling input-output gates. This stops all input-output operations and allows the program control to execute additional internal maintenance commands to test specific input-output functions.

Commands which gate to and from maintenance center registers are also used by the on-line control unit to both control and monitor actions performed in the off-line unit. For example, outputs of off-line check circuits can be observed by looking at the maintenance center error register.

4.3.2 *Diagnostic Programs*

It is important to order diagnostic tests so that a command or circuit used to test another command or circuit has itself been previously tested. If this rule is followed, the only circuitry under suspicion if a given test fails is the circuitry currently being tested and only a single printout indicating what test failed and how it failed is required to provide diagnostic information. Good test access from the on-line to off-line control unit allows tests to be ordered in this manner in most cases.

Figure 8 is a simplified flowchart of the diagnostic sequence. First, on-line to off-line access is tested both via the maintenance center and external commands. Success of these test blocks insures that sufficient on-line to off-line access is available to test off-line circuitry in detail. The next test blocks use this access to test various parts of the off-line control unit including command logic, the program store, and the call store. Near the end of the diagnostic sequence, enough off-line circuitry has been tested so that diagnostic programs can be run entirely in the off-line control unit. Tests such as input-output diagnostics are run in this manner under control of the on-line control unit. In many cases, these same tests are also used in periodic and mismatch detection.

The entire diagnostic sequence is always called whenever control complex diagnostics are called in automatically. This insures that faults are caught by the proper diagnostic test and that a meaningful printout is produced. No attempt is made to use the results of trouble recovery programs in order to shorten the time required for diagnostic testing since diagnostic test time (about 30 seconds) is an insignificant part of the total time required to repair a fault.

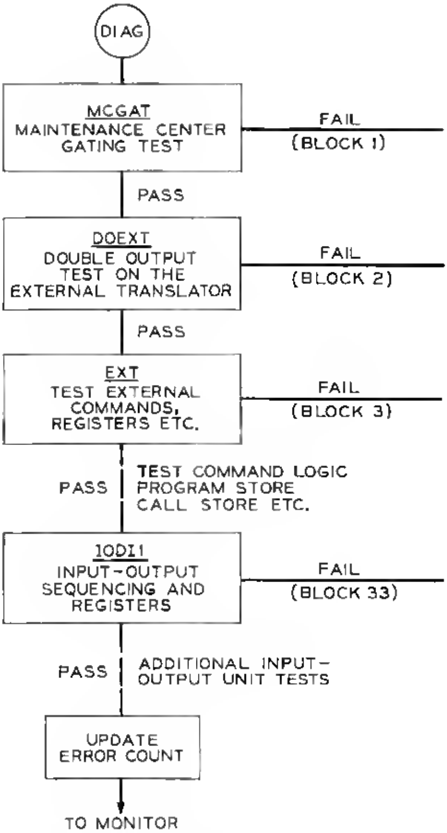

Fig. 8 — The diagnostic sequence.

In certain cases, after a given diagnostic test failure, up to two other diagnostic tests further down in the diagnostic sequence may be automatically requested in order to improve resolution. In all cases, if more than one test fails, the diagnostic printout is generated by the failing test closest to the end of the diagnostic sequence.

As shown in Fig. 9, a test block is subdivided into test segments. Numbers associated with test blocks and test segments are used to uniquely identify the failing test in a teletypewriter printout. A typical diagnostic printout shown in Fig. 10 contains a block number and segment number identifying the test that was in progress when the printout was formed. It also contains a data word indicating exactly how the test failed; for example, what bit of a particular register is bad. This information is used by the craftsman in referenc-

ing the translation section of the trouble locating manual in order to find replacement circuit packages.

A failure in a circuit containing state memory may in the worst case leave the circuit in any one of 2^N states if N memory elements are present. If no attempt is made to initialize this state memory before a diagnostic test is run, up to 2^N different diagnostic printouts may be generated. In general, good on-line to off-line communications allows setting of state memory to a single consistent state. This means only one printout will be produced for a given fault independent of the control unit state at the time of failure. For certain faults, it is not possible to establish a single initial state before diagnostic testing is started. A fault of this type may produce a different printout for each possible initial state. In these cases, an attempt is made to list all possible printouts in the trouble locating manual.

Often, in order to obtain good diagnostic resolution, it is desirable to perform combinational checks of logical rather than sequential operation, since combinational checks only depend on the present inputs and not on the past machine states. However, much of the control unit normally operates in a synchronous sequential manner:

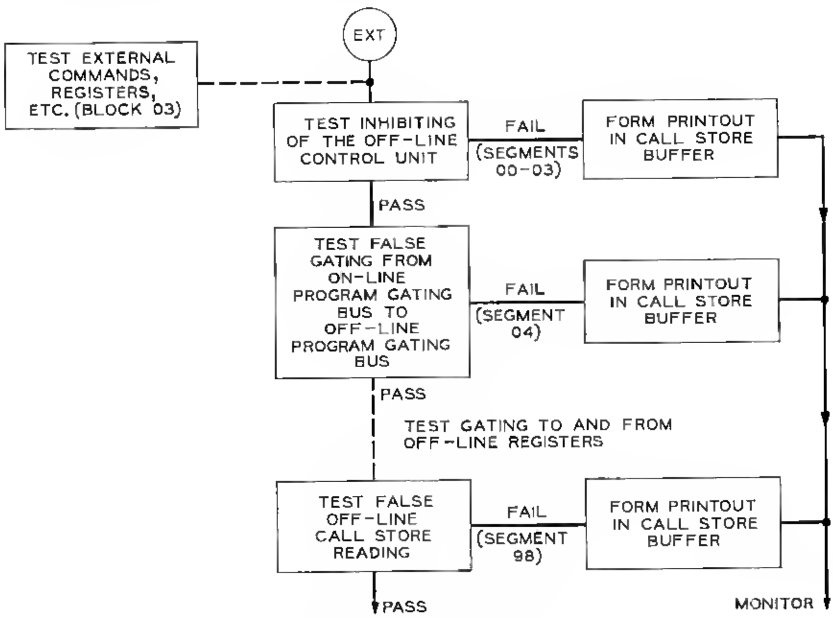

Fig. 9 — A diagnostic test block.

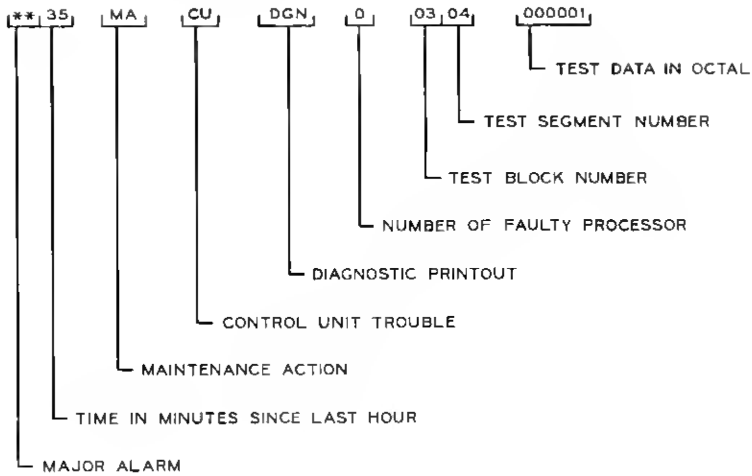

Fig. 10 — A typical diagnostic printout.

operations performed during clocked intervals are dependent not only on present inputs but also on past machine states. An operation performed during such a clocked interval can be checked combinationally if the state memory remembering the past machine states can be gated to by program and if the machine can be prevented from cycling through the sequence. Figure 11 is an example of circuitry in the input-output unit which is checked in this manner. The following steps are used to check gate SETB.

(*i*) Set a control flip-flop to prevent clock pulses from enabling input-output logic gates or resetting flip-flops.

(*ii*) Set the A flip-flop and clear the B flip-flop by direct gating via the program gating bus.

(*iii*) Enable clock signal POON for one clock interval by executing a special internal maintenance instruction.

(*iv*) Check to see if the B flip-flop is correctly set via program gating bus access.

Failure of the B flip-flop to be set results in a generation of a diagnostic printout which gives the block and test segment number of the failing test plus a test result data word.

The program timer which is an asynchronous seqential circuit is also checked in a similar manner except that, instead of stopping the

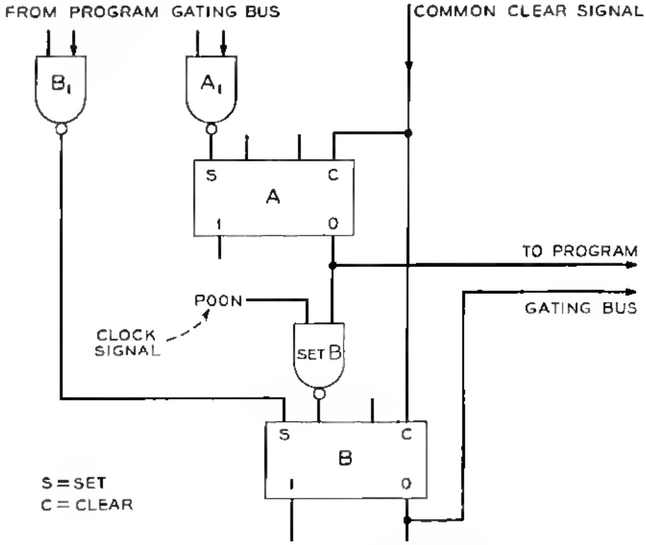

Fig. 11 — Combinational testing.

clock, leads from a control flip-flop are used to cut feedback paths and prevent sequential operation while testing is being performed.

4.4 *Error Strategy*

A control complex error is defined as a trouble which is detected by either circuit or program means and then disappears when diagnostic testing is performed. Errors can be produced by such things as a fault causing a marginal circuit condition or by noise which changes a 1 to a 0 or vice versa. Errors had to be considered when designing control complex maintenance programs in order to prevent them from adversely affecting call processing and to insure that a repeated error caused by a marginal circuit fault results in some attempt at corrective action.

4.4.1 *Mismatch Detection*

Mismatch detection tests attempt to minimize the effect of errors or standby faults on call processing by turning on input-output work (both circuit and program) very soon after the initial mismatch. Figure 12 shows detection test ordering and actions taken at various times after the initial mismatch. Note that the off-line control unit is inhibited and a test of the input-output is performed immediately

after mismatch. If this test is successful, input-output digit scan functions are resumed. After an additional short test of program control logic (approximately 5 milliseconds after mismatch), the input-output 25 millisecond interrupt is allowed to resume.

Allowing the input-output unit and the 25 millisecond interrupt program to resume operation very soon after the mismatch, prevents incoming information from being lost when no solid fault is present in the on-line control unit.

4.4.2 *Repeated Errors*

The base level maintenance monitor keeps a count of the number of times automatically initiated control complex diagnostics return an all-tests-pass indication. If this count exceeds a fixed threshold in a ten-minute interval, further tests are initiated and no further automatic attempt is made to return to synchronization. Thus, some pro-

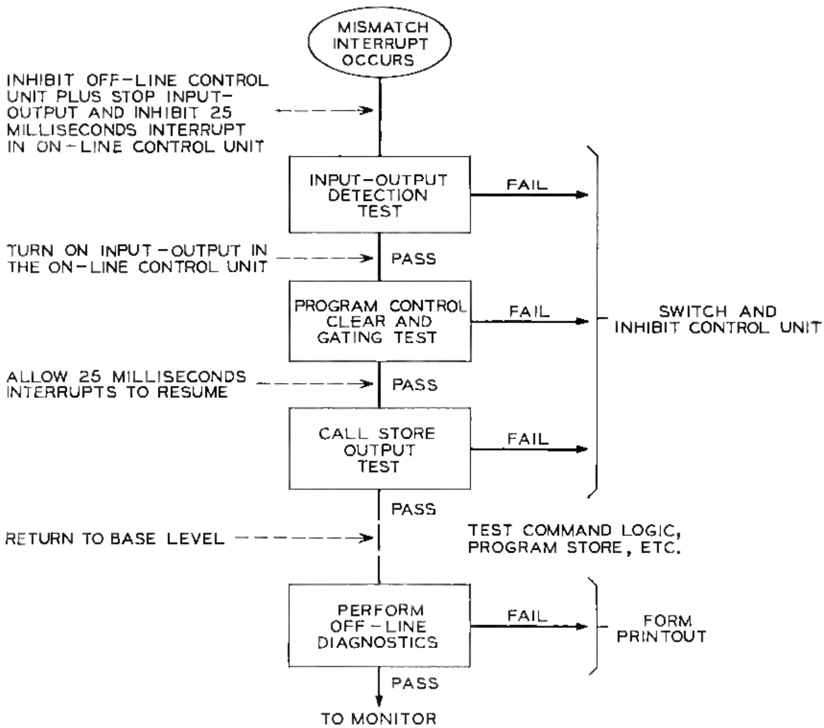

Fig. 12 — Mismatch trouble recovery.

tection is taken against transient and intermittent faults overloading the system.

V. PERIPHERAL SYSTEM MAINTENANCE

Both duplication and engineered redundancy are used for reliability in the peripheral system.[1,3] Duplicated control circuitry (controller) is used in the peripheral system wherever a trouble would affect a significant portion of the equipment. Either controller may be accessed from either control unit. Peripheral decoders, each of which controls up to four trunk or service cricuits, are not duplicated. Each may also be accessed from either control unit. Network links, trunks, junctors, and service circuits are provided in sufficient numbers that a faulty unit can be avoided without significantly affecting service.

Troubles must be detected quickly and the faulty unit identified and removed from service. Several troubles may have to be tolerated at the same time, including those induced by the craftsman when attempting repair or making additions to the peripheral system. Maintenance programs provide a "best reasonable" mode of operation and craftsman interface. Extensive and generalized troubleshooting facilities are necessary because of the frequent equipment additions to the system and the ratio of wired-in circuitry to replaceable plug-in circuit boards.

5.1 *Trouble Detection and Recovery*

Many of the troubles in the peripheral system are detected by check circuitry during the normal execution of an order to the periphery. This is especially true of troubles that have a significant effect on the system where rapid detection and recovery is most important. Some troubles are detected by the call programs which check for expected results at strategic points in a call, or "become suspicious" at unlikely occurrences.[2] They may initiate further tests immediately or provide results to be accumulated for further actions when an error threshold is reached.

The remaining troubles usually do not seriously affect service and are detected by manual and automatic routine exercise, audits, and trouble reports.

5.1.1 *Scanner Troubles*

The scanner organization, duplication, and interconnection are described in Refs. 1 and 3. Each of the duplicated scanner controllers

may be accessed by either control unit. For some troubles in scanning, a controller would be removed from service. For other troubles, a control unit would have to be removed from service. Since interrogate and readout windings are not duplicated, there are troubles which affect a single row of 16 ferrods, or a colmun of up to 64 ferrods for any of the four controller-control unit combinations. This prevents use of these ferrods.

Detection and recovery actions are indicated in Fig. 13 with the separation between circuit and program functions. Troubles in the selection of a scanner or row are detected by check circuits in the input-output or scanner.[1,3] The scanner may be accessed by a program order or by the autonomous input-output logic in the control unit which scans for digits and line originations.[1]

A program scan order is immediately followed by a program check for an error indication and the trouble recovery program is called as a subroutine on error. For an autonomous digit scan error, the trouble recovery program is entered by an interrupt during which autonomous scan functions are stopped. The autonomous line scan stops when a new origination, or an error, or a last row is detected. The 25 millisecond interrupt program which controls this function detects such a trouble later on rescan by a program order.

Scanner output troubles are not detected by check circuits. Some of these are detected by defensive design in programs which use the scanner. For example, supervisory scan programs suspect trouble for supervisory changes in successive rows, or more than one change in a row and call an immediate scanner output test as indicated in Fig. 13.

Some output troubles cause a control unit mismatch on a subsequent call store read or write. An output test is performed for all scanners following a mismatch. Detection of other troubles relies on routine exercise with the diagnostic test.

Individual ferrod troubles are not detected by any of these checks. These troubles show up as faulty operation of the circuits to which these ferrods are assigned.

5.1.2 *Scanner Trouble Recovery*

The trouble recovery programs, after verifying a trouble, first try the other controller and then the other control unit in order to identify the faulty unit. The order that failed or the test that detected the trouble is used for these attempts. A bad interrogate or readout winding is assumed and recorded if none of these tries are success-

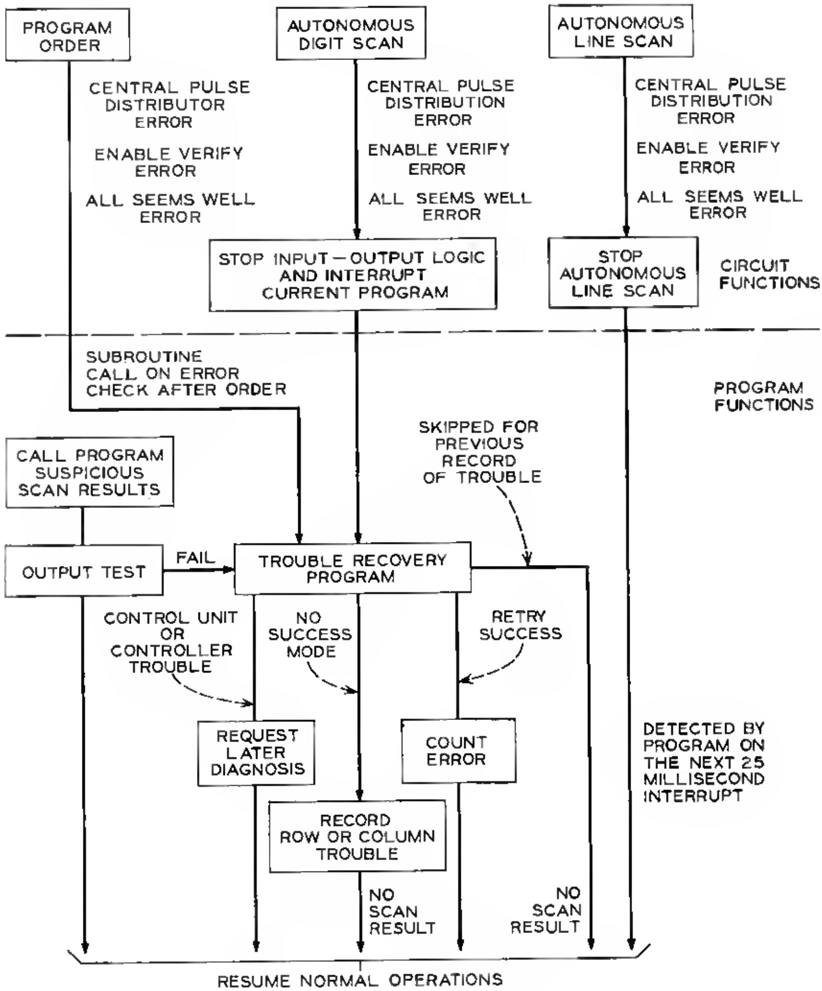

Fig. 13 — Scanner trouble actions.

ful. Once a controller or control unit is marked out of service, it will not be restored automatically or used in a later trouble recovery attempt unless the number of bad rows or readout windings becomes excessive. When the number of errors recorded becomes excessive, the out-of-service unit is restored automatically and the on-line unit removed from service. This allows the corrective action for a second

trouble to override that for the first if the second trouble has a significant effect on service.

In resuming normal operations, a later diagnosis is requested for any new trouble found, and the call operations may be cleared or skipped if a row or column cannot be scanned. For example, a row trouble detected by supervisory scanning would cause that row to be skipped, whereas a row trouble detected by digit receiving would cause the digit receiver and path to be idled and a reorder tone connected. A test of the circuits in the call to which the ferrods are assigned would be initiated.

5.1.3 *Network Connection Troubles*

Orders to the network require several milliseconds to complete. In order to allow efficient use and control of the network access, orders are sent by the program to all networks in an order execution cycle of up to 10 milliseconds every 50 milliseconds.[2]

As indicated in Fig. 14, some check results are available immediately after the network order and path data is sent to the network.[1,3] Other check results are not available until the network order has had time to complete its operation. These latter check results, which are indicated by status ferrods, are checked for all network controllers just before beginning a network order execution cycle every 50 milliseconds. Any errors that have occurred on the last order execution cycle are known at this time and cause the trouble recovery program to be started.

5.1.4 *Network Trouble Recovery*

Each network order attempt by the trouble recovery program will take at least 50 milliseconds and so must be interleaved with call processing. The trouble is verified by retrying the order. The peripheral order buffer from which the order was sent must be determined so that the call may be stopped and the path and order data obtained. The other calls are not affected. The order is retried first with the other controller, if in service, and then with the other control unit, if synchronized, and the controller or control unit removed from service if found bad.

Since a sequence of network orders are sent before results are checked, a control unit fault may result in several controller troubles from that sequence of orders. In this case, the other control unit is tried first to minimize delays. In other cases, controller trouble indica-

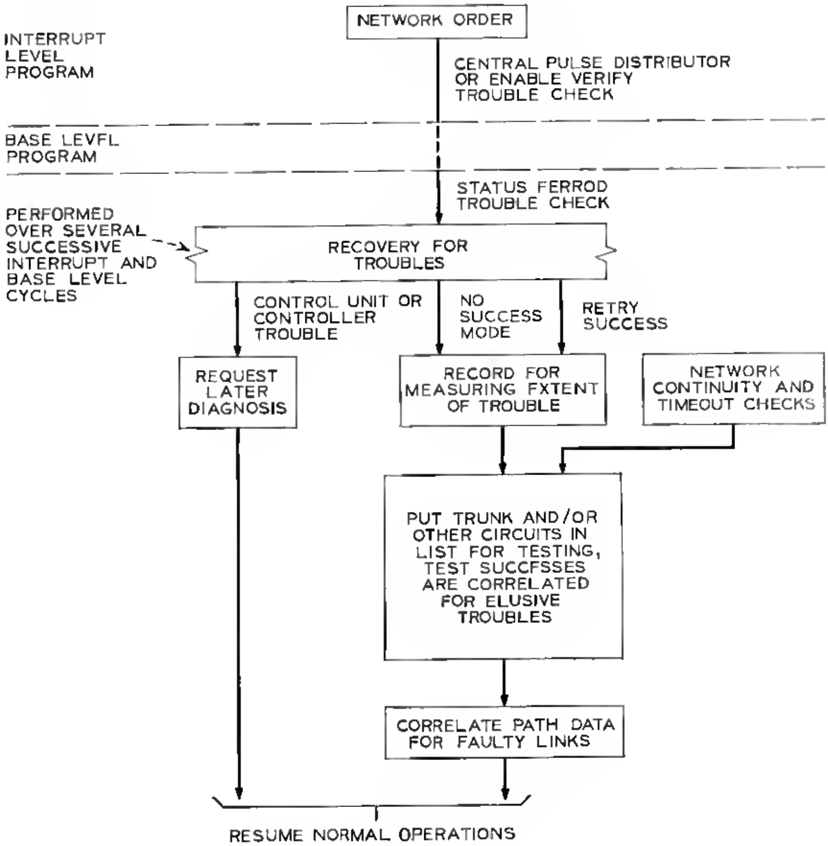

Fig. 14 — Network trouble actions.

tions are handled one at a time and a second trouble occurrence while resolving the first, stops all order execution until the first trouble is resolved. The controller status ferrods may indicate trouble such as loss of power or input noise when no order was sent. In these cases, no peripheral order buffer tbat accessed the controller will be found, and the entire sequence of network orders for that execution cycle is repeated to verify the trouble and try other combinations of controller and control unit.

Trouble indications may also occur because of nonduplicated network circuitry and the order will not be successful with the duplicate controller or control unit, or possibly the duplicate controller or control unit may have been left out of service by a previous trouble. Path data are accumulated in these cases to determine the extent and fre-

quency of the trouble. Faulty links are removed from service through correlation techniques. If the trouble is extensive in the frame and affects many input terminals, the other controller or control unit is automatically restored to service, as was the case with scanners. A record of the number of peripheral units of any type with extensive trouble with either control unit is maintained in this way so that the best control unit can be favored.

Lack of continuity in the network is usually detected by call processing. Path data for no continuity are correlated with that for other path troubles so that faulty links can be removed from service.

After a successful network trouble recovery attempt, the operations for that call are continued. If the network trouble recovery is unsuccessful, the call is torn down and a reorder tone is connected where possible.

5.1.5 *Trunk and Service Circuit Access Troubles*

The central pulse distributor and its supplementary pulse distributor are used to change trunk and service circuit relay states. Selection and output troubles for these units are detected by check circuits when program orders are sent, and the trouble recovery actions are similar to that described for scanners. A central pulse distributor trouble may require use of the other control unit whereas a supplementary pulse distributor trouble may require use of the other controller or, for some troubles, the other control unit.[1,3] It may not be possible to find a successful configuration for some output troubles. In these cases, the output number is recorded and the circuits that are assigned to that output cannot be used. Trunk and service circuit troubles may also show up as troubles in setting up a network connection or in a time out of some operation in the call where there are several possible sources of the error. When such circuits are possible sources of trouble in a call, they are put in a list for testing. The network links and those circuits which pass their tests or which cannot be tested are correlated on successive troubles as indicated in Fig. 14 to help isolate the source of the trouble. Various operational trunk and service circuit tests are further described in Ref. 2.

5.2 *Diagnostic Organization and Use*

5.2.1 *Common Controllers*

The network, scanner, and supplementary pulse distributor controllers are tested by a sequence of functional tests. For example, the functional test blocks for the scanner controller are:

(*i*) Access test with proper addresses, observing check circuit results for trouble.

(*ii*) Check circuit test using illegal addresses to see if the check circuits are capable of indicating trouble.

(*iii*) Output test using a test signal that induces outputs on all 16 readout leads.

Each of these functions is relatively independent of the others and the trouble number is formed from results of the first functional test block which fails. Several test results within a functional test block are usually combined in the test number to improve the resolution and provide error data to help the craftsman when the *Trouble Locating Manual* listing is insufficient. For example, in the scanner controller, the one-out-of-64 ferrod rows is selected by an 8-by-8 coincident core matrix.[3] The two one-out-of-eight selections are received over 16 leads of the peripheral unit address bus. In the access test block, all 64 rows of the ferrod matrix are accessed in sequence. The OR function of the proper peripheral unit address bus contents for all failing addresses provides a 16-bit error data field (6 octal characters) which is part of the trouble number in the diagnostic message shown here:

35 MI MS DGN 02 1 — 1264 004377

Trouble number

Diagnostic for Master Scanner 02, controller 1

Maintenance Information

Message occurred 35 minutes after the hour

In a particular test block, failure modes, such as bus receiver or core driver faults, are easily analyzed by class when designing the program for determining the associated trouble numbers. These failure modes can then be ignored in the program design and analytical generation of *Trouble Locating Manual* entries for any functional test block that follows in the sequence.

Peripheral system access troubles may be caused by faults in the control unit access that are not detected by the control unit diagnostic program. The trouble recovery programs would normally leave the faculty control unit off line. The same functional tests that are used for testing a controller are also used for testing the access to a con-

troller from the off-line control unit. Additional tests are needed in some cases for testing input-output control circuitry that is not tested by the control unit diagnostic program.

When testing the control unit access, the orders are executed from the off-line control unit, and the first character of the trouble number is modified so that different equipment may be indicated by the *Trouble Locating Manual* listing. The listing for these trouble numbers is only accurate if the trouble is in the control unit access and not in the controller, so the request for diagnosis from the off-line control unit is rejected if there is a controller trouble from the on-line control unit. In addition, the off-line control unit is automatically diagnosed and must pass before the access is diagnosed. Diagnosis of a controller or controller access is also rejected unless the duplicate controller is in service for call processing use. For simplicity, only one diagnosis may be in progress at any one time and it will be aborted if a new trouble occurs while it is in progress.

A separate *Trouble Locating Manual* is provided for each type of peripheral unit.

5.2.2 *Use of Diagnostics*

The diagnostic programs are also used for restoring equipment to service after repair, for giving the peripheral system automatic routine exercise, and for testing new equipment additions.

Controllers and their access are tested about once a day in a low traffic period, except for scanner output where service affecting troubles are not detected by check circuits while in use. These are tested more frequently (about every minute or faster, traffic permitting).

Remote execute facilities, with pushbuttons and indicator lamps located on various frames throughout the office, allow tests previously specified by teletypewriter to be stepped through or repeated by operating a pushbutton. Pass-fail results are indicated on lamps which are part of the remote execute facility.

5.3 *Peripheral System Growth*

New equipment added in an operating system for growth and for a new installation must be tested thoroughly before it is put into service. In an operating system, the installing and testing should have a minimal effect on service. Troubles that occur during shipment, installation errors, and any troubles that did not show up in factory testing

must be corrected at this time. The use of connectors for interframe wiring reduces the installation interval. It also reduces the wiring errors since the connector wiring can be tested at the factory.

The diagnostic test programs described are used where possible to help locate these troubles. The *Trouble Locating Manual* is not satisfactory for this purpose because several troubles and wiring errors may be present. Entries in the *Trouble Locating Manual* were formed by predicting test results for a single failure that could occur in an operational system. Specifying test results for combinations of trouble is impractical and the craftsman must trace the symptoms manually. The diagnostic program provides a means to exercise all functions of the equipment and identify the trouble symptoms. The diagnostic program may print out a failing order or functional operation, for example, instead of a trouble number. Tbe order or functional operation may be requested, with the repeat option if desired, and the operation observed by oscilloscope or other test instruments. This method of locating faults is also useful for troubles that occur in operation in the few cases where the *Trouble Locating Manual* is insufficient.

Additional test programs and manual test procedures are needed for some of the possible troubles at installation. Network link troubles, which are identified by error correlation techniques in normal use, require a program test for any new network frames added. Translation data in the memory, which relates to equipment in the office, changes when equipment is added, and must also be verified.

Such units as the scanner and supplementary central pulse distributor tie into the common peripheral unit address bus and scan answer bus. The off-line control unit is not usable until the bus leads are connected and verified for correct wiring, polarity, and waveform in both directions from the new frame added. Interframe bus connectors help to minimize the exposure of the system to other troubles during this operation. If other troubles do occur, the system will stabilize in a "best" operating mode, and the craftsman may reinitiate this decision process, if necessary, after restoring the bus integrity.

Half of a scanner ferrod matrix (512 ferrods) may be added during growth. In this case, the output leads must be disconnected and the additional ferrods added in series with minimal effect on normal use of the other ferrods. Here again connectors are used to allow rapid change over and recovery in case of trouble in matrix addition. The repetitive test mode allows rapid indication of a trouble on pass-fail

lamps and provides a diagnostic printout so that the craftsman can minimize the time that a faulty matrix addition is connected.

The network may be increased in size by the addition of a network control and junctor switching frame or by adding line or trunk switch frames to an existing network control and junctor switching frame.[3] The network control and junctor switching frame contains new network and scanner controllers. Both the access to these from the off-line control unit and the controller themselves are tested using the diagnostic tests. Controllers access to the line-trunk switching frame is also tested with the diagnostic tests. In both cases, the network links are tested with a special network fabric test program. While testing the network control and junctor switching frame, the junctors are connected back into the same network control and junctor switching frame at the junctor grouping frame in a standard test pattern. A junctor reassignment over all network control and junctor switching frames must then be performed before the new network control and junctor switching frame can be put into service. The junctor translation tables are updated in memory to indicate both the existing assignments and the new assignments. The junctors are segmented into four parts at the junctor grouping frame and only one of the segments is removed from service at a time for junctor modification. A verification of the new junctor connections with the translation tables and a test of circuit junctors is made for each segment before those junctors are put back into service. After the reassignment is complete, any new trunks, service circuits, and lines to be added are tested and put into service. The common control frames such as the scanner or supplementary pulse distributor are, of course, tested before the circuits they monitor or control are tested.

VI. MAINTENANCE MONITOR

The base level maintenance monitor is the primary noncall processing executive program in the office and all maintenance programs come together through it. The responsibilities of the monitor include:

(*i*) Recognizing changes in the system's state and the initiating a proper response to a state change (state detector).

(*ii*) Controlling almost all base level maintenance programs in the office (scheduler).

(*iii*) Monitoring all maintenance input messages from the craftsman.

(*iv*) Initiating periodic work that must be done on a time schedule.

(*v*) Miscellaneous functions such as timing and controlling system

alarm conditions and checking the integrity of the entire base level scan.

Figure 15 shows of the "information flow" through the main parts of the monitor.

6.1 *System State Detector*

State changes in the system are either caused by trouble detection mechanisms or are induced by the craftsman from the maintenance center or via the teletypewriter.

It is the state detector's responsibility to look over the last scan and detect and take action on the occurrence of: (*i*) a mismatch interrupt, (*ii*) an input-output trouble recovery action, (*iii*) a system initialization or restart, (*iv*) the failure of an automatic error detecting circuit or a periodic control unit detection test in either control unit, and (*v*) manually initiated changes such as putting the system into the manual mode of operation.

When the state detector sees that a change has taken place, it initiates an output message identifying the change, records the occurrence of a control unit switch, and lets the craftsman known what automatic action will be taken.

In addition, the state detector feeds state information to both the maintenance program scheduler and the teletypewriter maintenance input message monitor which enable these programs to control items already in progress in the system or coming into the system via the teletypewriter. For instance, when a craftsman puts the system into the manual mode, the state detector feeds the necessary information to the maintenance program scheduler to inform it that he has taken control over the off-line control unit, and no automatically initiated maintenance program from then on should interfere with him.

The state detector also guarantees a consistency of hardware control in the system. As an example, when the craftsman goes to the manual mode, the state detector blocks all interrupt signals from the maintenance center. If the craftsman wishes to generate a manual interrupt, he must then type in the necessary input request message which will store what the craftsman wishes to do when the interrupt occurs and release the interrupt "block."

6.2 *Maintenance Program Scheduler*

The heart of the maintenance monitor is the maintenance program scheduler. The scheduling algorithm is fairly simple and is tailor fit

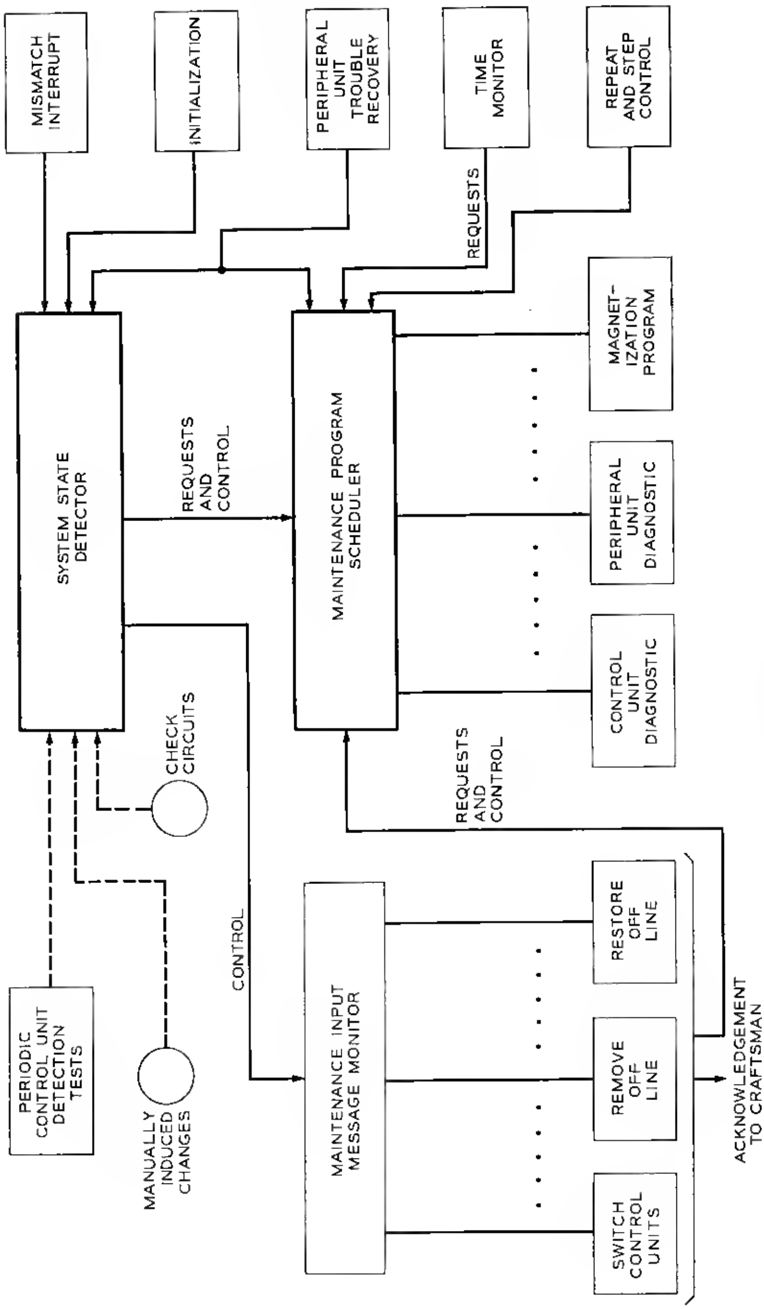

Fig. 15 — Maintenance monitor information flow.

to the type of programs it controls. These programs involve interface with the craftsman and are all multiscan (that is, they are allotted only a certain amount of real-time per scan and take many scans to complete). In general, the scheduler will allow only one such program to be in progress in the system at any time. This avoids both confusion by the craftsman and interference problems which can result from running these programs concurrently. For instance, control unit diagnostics program assumes it has absolute control over the off-line control unit during the entire time it is in progress and no other program can change off-line register or memory contents. Off-line peripheral unit diagnostics assume the off-line control unit is healthy and can produce misleading information were they to be initiated while control unit diagnostics are in progress.

The basic "one-at-a-time" algorithm of the scheduler should also help desensitize the system to potential troubles which show up in different areas depending on the time of occurrence.

The scheduler operates on a four-word memory block representing a matrix of four rows and 16 columns. Each maintenance program is assigned one or two column positions and has associated with it a "request," an "in progress," an "allow," and an "abort" bit. Figure 16 is a picture of the matrix showing the matrix positions of the programs under control of the scheduler. Any initiator of one of these programs (teletypewriter or automatic) simply sets the proper request bit in the matrix. The scheduler will then analyze this request with regard to whether the program is "allowable" in the present system state (the allow word is initialized every scan by the system state decoder) and whether a higher priority maintenance activity is now in progress in the system. The priority of the various programs is represented by their column positions in the matrix. This *a priori* priority structure can be determined by considering both the programs themselves and the request source. The various maintenance programs in the system operate in a realm of concentric circles in their importance to the system and in their assumptions (that is, off-line peripheral unit diagnostics assume that the off-line control unit is healthy). Automatic requests are triggered by changes in the system state and by automatic trouble detection signals; consequently they are more urgent than teletypewriter requests.

The scheduler will take the abort entry associated with each program if: (*i*) a higher priority request enters the system while it is in

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INPROG		PU EXER-CISE	CU EXER-CISE	SCW TRANS UP-DATE		OFF PU DIAG TTY	ON PU DIAG TTY	CU DIAG TTY		UP-DATE & SYNC			OFF PU DIAG AUTO	ON PU DIAG AUTO		CU DIAG AUTO
REQEST																
ALLOW																
ABORT																

CU = CONTROL UNIT
DIAG = DIAGNOSTIC
AUTO = AUTOMATIC
PU = PERIPHERAL UNITS
SYNC = SYNCHRONIZATION
TTY = TELETYPEWRITER
SCW = SINGLE CARD WRITER
TRANS = TRANSLATION
INPROG = IN PROGRESS
REQEST = REQUEST

Fig. 16 — Maintenance program scheduler matrix.

progress, or (*ii*) a change in the system state occurs and the state detector marks it nonallowable.

Abort routines are necessary to prevent erroneous decisions by maintenance programs. These decisions can result in the improper removal of equipment from service and in misleading information on the teletypewriter. They also serve to let the craftsman know what is happening in the system. Further, in the case of a higher priority request, the time cannot be taken to let the lower priority activity finish but the request can be held until the abort is complete. The abort programs, if necessary, can distinguish between the two reasons for entering the abort by looking at the allow bit. For instance, the abort for the magnetization program (single card writer translation update) will not force the craftsman to start from the beginning if it finds a higher priority request entered.

Various minor options are available with the scheduler. By use of logic masks, subsets of maintenance programs can be allowed to run concurrently. The craftsman, via a teletypewriter overwrite, can control the state detector and either allow or not allow a program to run until he tells the system otherwise.

The scheduler also takes care of the control of "repetitive" and

"step" functions (remote execute facility). The craftsman can specify the repetitive or step option on an input request for a maintenance program. The scheduler will then either continuously repeat, or repeat on signal the program requested and provide output on the teletypewriter or in lights depending on which option was chosen. The scheduler will allow only one repetitive or step function to be in progress at any one time. The repeat or step control is very useful in the repair procedure.

The maintenance programs not under control of the scheduler include the service circuit and trunk tests, and tests associated with the ringing and tone plant and the automatic message accounting unit. Many of these tests are progress mark routines operating out of transient call records. The tests do not require the complex control of the programs under the scheduler and do not interfere with other maintenance activity in the office. As far as the maintenance monitor is concerned, the tests behave like a typical call in progress. The monitor, however, still is responsible for initiating these tests periodically and the tests must be aware that a major maintenance action has occurred.

6.3 *Maintenance Input Message Monitor*

The maintenance input message monitor routes the various messages from the teletypewriter to the proper subprograms and performs validity checks common to all inputs. If the craftsman specified a priority on the input or used the repetitive or step option, these items are checked for validity. In addition, the present system state computed by the state detector can be compared with the states allowable for a given input and the message rejected if the state is not correct.

Input messages to change the system state (switch control units, remove off-line equipment from service, restore off-line equipment to service, and so on) or to provide system status information, are processed wholly within the monitor. Messages that request programs under the scheduler's control merely set the proper request bit in the matrix.

6.4 *Time Monitor*

The time monitor initiates all periodic activity that operates on a time schedule. It must deal with time spans from seconds up to once a day.

Status information at the maintenance center, such as the stand-by lights, is updated once per second and small interval timing is provided for traffic measurements.

The time monitor serves to initiate periodic exercises on the control until and the periphery during low traffic hours. These programs seek to find failures by exercising all equipment, thus avoiding the unnecessary failing of calls. The control unit exercise checks all the special maintenance circuitry in the processors, performs store margin tests and checks the ability of the control units to switch.

6.5 *Miscellaneous Functions*

The alarm monitor keeps track of various alarm conditions for the office, such as fuse failures, and times local alarms if the alarms are transferred to a remote location. The fuse ferrods are checked at intervals from the time monitor.

The maintenance monitor is responsible for resetting the program timers and checking the integrity of the entire base level scan. Software checks are made to detect program skipping and the program timers protect the system against program looping.[1]

During every scan the monitor calls in the teletypewriter base level processing program and programs which deal with trouble correlation and measurements. Counts are kept of almost all troubles in the system ranging from customer receiver troubles to failure of control unit diagnostics. These service and performance measurements ("plant") should give the craftsman a good picture of the total "health" of the system.

VII. DATA MAINTENANCE

One of the primary maintenance objectives for any electronic switching system is to insure the best possible integrity of call store information in the system during periods of trouble. Call store mutilation can result from hardware faults and intermittents, and from program bugs. During periods of nonsynchronous operation, the mismatch detection mechanism is lost to the system and the detection of some hardware troubles will be delayed until a specific periodic test finds them (that is, those that would not be caught by the other automatic error detecting circuits). In this situation, data multilation can occur between the time the trouble occurs and the time it is detected.

System response to transient and intermittent failures depends on programs recognizing a high error signal occurrence over a period of

time. Very infrequently accessed branches of the program can have bugs which will mutilate some memory despite the best effort in program debugging prior to cutover. It is interesting that the mismatch detection mechanism and synchronous operation is not much help for program bugs since for most bugs the processors will maintain synchronization. In this sense, a program bug is equivalent to two simultaneous and identical hardware failures.

7.1 *Preventive Techniques*

The potential effect of any of these problems on memory is highly dependent on the basic program algorithms of the system. The ease of communication among programs, the absence of linked list structures, and the per call assignment of major blocks of memory significantly aids the task of data maintenance. For instance, the progress mark approach to call processing taken by the No. 2 ESS assigns an arbitrary block of call store (transient call record) to each call which remains fixed while it is being processed ("transient"). Additional storage associated with the call is added as necessary (peripheral order buffers and originating registers). Each progress mark routine is entered with the transient call record or peripheral order buffer block address as data, and the routine works within the block with relative addressing. The scope of a progress mark routine is then a small set of data relating to a single call.

In addition, defensive programming techniques are used throughout the No. 2 ESS. Table indexes obtained from call store are range-checked or small tables are made complete to cover all possible index values with invalid indexes pointing to error routines. Programs that transfer, based on the call store, check the address for all zeroes first in case the recovery programs had zeroed this word so that they will not continue to transfer wildly. Translation information is obtained by accessing a master table index which will insure that, with bad data in call store, program instructions will not erroneously be read as data with a resultant parity error failure. The intent of such defensive programming techniques is to allow processing to continue in the face of bad data and limit the effect of the data to one or a few calls.

7.2 *Corrective Techniques*

Despite the algorithms employed and the defensive techniques used, programs are still required which will detect and recover from

bad data. In the No. 2 ESS, these involve (*i*) audit programs, and (*ii*) system recovery or initialization programs.

7.2.1 *Audits*

The No. 2 ESS call store memory contains many items of redundant information in different forms, some associated with individual calls and other information primarily equipment oriented. The memory also contains links connecting blocks associated with a call. It is the function of audit programs to ascertain whether these various items in memory are consistent.

Separate audit programs are written for the various memory blocks such as the transient call records, terminal memory records, line status bits, originating registers, peripheral order buffers, and the network map.[2] For example, the originating register audit program checks for a correct linkage from the originating register to a terminal memory record and transient call record. When an audit program finds inconsistencies, it attempts to idle the memory blocks and, if possible, the corresponding equipment. The audit programs are called in periodically from the time monitor, can be initiated from the teletypewriter, and form an important part of the system recovery strategy.

7.2.2 *System Recovery*

The system recovery program (or "initialization" program) is triggered by hardware (program timers[1]) upon the occurrence of a control unit switch when the system was not running in synchronization. Multiple control unit switching while in the synchronous mode will also activate it. Control unit switching can be caused by bad data and software bugs as well as hardware failures. For example, the program timers will switch control units if the program hangs up in a loop. The control unit switch itself is the proper response to a hardware failure and the recovery program's job is to:

(*i*) Insure the new on-line call store is reasonably consistent with the state of the periphery regardless of the cause of the control unit switch. When the off-line control unit is inhibited and is not under the control of a craftsman, the base level maintenance monitor activates circuitry which causes the off-line call store to automatically track the on-line call store. If a control unit switch occurs, the early "phases" of recovery can assume the new on-line call store is consistent. If, however, a switch occurs while the craftsman is in control,

the entire new off-line call store must be moved across to the new on-line call store.

(*ii*) Clear memory in increasingly larger segments in an attempt to stabilize the system if software is at fault.

A typical sequence of recovery attempts would involve:

(*i*) Isolating the program in control of the system at the time of the control unit switch, and taking appropriate action on memory blocks associated with the program (either clearing the blocks or marking them bad for later action).

(*ii*) Calling in the audit programs in an emergency mode.

(*iii*) Clearing all transient data in the call store while preserving the stable call records.

The craftsman can force in the recovery program and he alone can trigger the initialization of the stable data. Any recovery attempt will notify the base level maintenance monitor to abort any maintenance program in progress in the system.

VIII. EXAMPLE OF SYSTEM TROUBLE

We will now go through a trouble example where a fault occurs in the input-output unit of the control unit affecting the access to a peripheral unit. We describe the sequence of actions for detection, recovery, discontinuing the troubleshooting that was in progress, diagnosis, and repair.

Assume that network controller 1 for line trunk network 2 is out of service and the craftsman is troubleshooting this controller. He has typed in a request to repetitively execute an order to tbe controller. Assume, at this time, that the system is in synchronism with control unit 0 on-line and a central pulse distributor enable translator gate fails (see Fig. 17). This failure is first detected by a program scan order to master scanner 3, controller 0.

8.1 *Trouble Detection and Recovery*

The failing scan order returns an indication which results in a program transfer to a maintenance recovery program. This program verifies the order failure and retries with duplicate controller 1 which, for the trouble specified, will also fail. The recovery program then switches control units and again retries the order which now will be successful.

The new off-line control unit 0 is marked out of service with bad access to master scanner 3 recorded. The following message is printed:

** 36 MA CU RMV 0 MS 03

Control Unit 0 Removed from service for faulty access to Master Scanner 03

Maintenance Action

Time in minutes since the last hour

Major alarm

Both controllers of the scanner remain in service from the on-line control unit 1. A request is made for diagnosis of the stand-by control unit 0 and its access to master scanner 3 controller. In addition, the base level maintenance monitor is notified to abort any conflicting activities. The trouble recovery program then returns control to the call program. Only a few milliseconds have elapsed since the trouble was detected and the scan order was accomplished, so service is not affected.

When the maintenance monitor gets control at the next end of scan, it will cause the repetitive order operation that the craftsman initiated to be aborted. The craftsman will be informed of this action by the pass-fail lamps both being dark, and by the following tele-

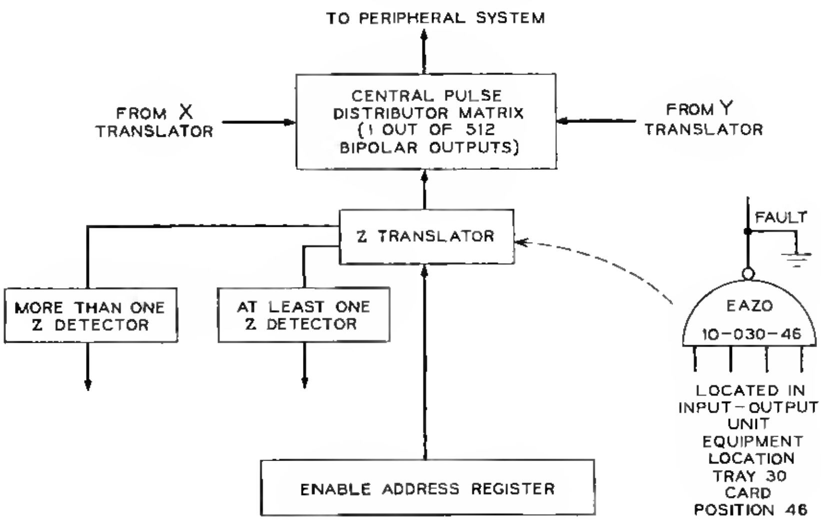

Fig. 17 — A control unit fault.

typewriter message:

36	MR	NW ORD 02	01 ABT
Minutes since the last hour	Maintenance Response related to a previous manual request	Network Order function for line or trunk switching network 02	Controller 0, from from off-line control unit 1, has been Aborted

8.2 *Diagnostics*

Once the abort is completed, the monitor will recognize the diagnostic request made by the recovery program and diagnostics will be initiated interleaved with call processing. In this case, control unit diagnostics will fail in an input-output circuitry test block.

As shown in Fig. 9, input-output circuitry is tested by test blocks located near the end of the diagnostic sequence. This means input-output circuitry can be tested by programs run entirely in the off-line control unit since almost all off-line program control circuitry has been previously tested.

The on-line control unit uses external commands to first set up an off-line program starting address and then to start the off-line program control. At some later time (after sufficient time to allow test completion), the on-line control unit looks at the state of the off-line unit to determine if the off-line unit passed or failed its diagnostic test. If it failed, the state of off-line registers is used to form the diagnostic printout.

Diagnostic test block 38 tests central pulse distributor circuitry in this manner. Internal maintenance commands are executed in the off-line program control with the input-output stopped in order to test the Z central pulse distributor translator. The enable address register is first set to an address which should select a particular Z translator gate. The translator is then enabled using a maintenance instruction which generates clock pulses for one clock interval. If the Z translator does not fire properly, one of Z check circuits will produce an

error signal: the "not more than one Z detector" or the "at least one Z detector." The "at least one Z detector" will produce an error when the EAZO gate is selected because no output can be produced. In test segment 12 of block 38, the off-line program control exercises all 16 Z translator gates and accumulates a data word which has a 1 corresponding to each translator gate which resulted in an "at least one Z detector" or a "not more than one Z detector" error signal. For the EAZO gate output ground failure, the data word is 0000000000000001 in binary or 000001 in octal code.

The off-line control unit stops itself when the Z translator data word is found to be nonzero. The on-line control unit finds that the off-line control did not successfully complete the central pulse distributor test and uses the off-line state to form a diagnostic printout. The block number (38) and the segment number (12), plus the data word 000001 in octal form, are used to form the diagnostic printout:

**	38	MA CU DGN 0	38	12	000001
Major alarm	Time in minutes since the last hour	Maintenance Action Diagnostic printout for Control Unit 0	Test block number	Test segment number	Test data in octal

The craftsman uses this diagnostic printout to look up the translation section of the *Trouble Locating Manual* to obtain a list of replacement circuit packs. Figure 2 shows the *Trouble Locating Manual* entry corresponding to the diagnostic printout obtained for the Z translator failure. Notice that the *Trouble Locating Manual* entry for 3812 contains a short explanation of the failure area. The circuit packs are identified by the circuit pack location (I0-030-46) and the circuit pack type (A403).

8.3 *Repair*

After obtaining the list of replacement circuit packs, the craftsman next requests continuous execution of the failing test block by tele-

typewriter:

MR CU:DGN:38!

Repetitive Control Unit Diagnostic request for block 38.

This request should produce a verification that the failure still exists by producing a teletypewriter printout identical to that originally obtained and should cause the fail light on the maintenance center panel to come on. This fail light is turned on by program each time the diagnostic fails. The maintenance center panel pass light is turned on if the test passes.

Circuit packs are replaced with this request running in the active control unit. Of course, off-line power must be removed while a circuit pack is being replaced. In this case, almost immediately after the first circuit pack (I0-030-46) is replaced and power is restored, the fail light should go out and the pass light should come on indicating the trouble has been fixed.

After the fault has been repaired, the craftsman can now type teletypewriter requests to remove the diagnostic test and to restore the off-line to service:

M SY:CLR!

Clear out repetitive request

M CU:RST!

Restore off-line Control Unit to service

These requests should turn off the out-of-service light on the maintenance center panel and put the two control units back in synchronism, after first successfully completing another test of the standby control unit and its access to master scanner 3 controller 0.

The craftsman may now return to the original problem in controller 1 of line trunk network 2 by again requesting a repetitive network order.

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